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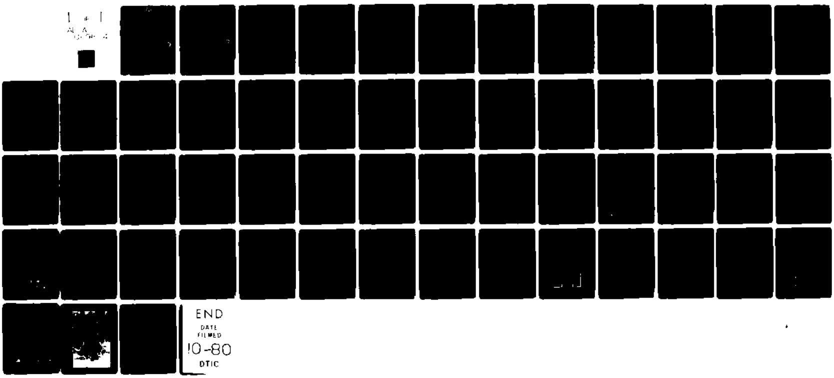

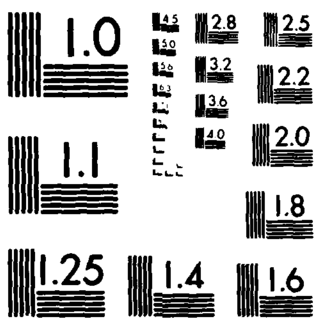

MICROCOPY RESOLUTION TEST CHART

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(6) RESEARCH AND DEVELOPMENT OF A CONTROLLED CAVITATION EROSION (trademark) (CONCAVER) DEMILLING SYSTEM FOR DEMILLING EXPLOSIVE WARHEADS.

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RESEARCH AND DEVELOPMENT OF A CONTROLLED CAVITATION EROSION (CONCAVER™) DEMILLING SYSTEM FOR DEMILLING EXPLOSIVE WARHEADS

1.0 INTRODUCTION

During the normal development cycle of an explosive weapon system, a method for the eventual removal of the explosive from the warhead must be developed. Then, when a particular weapon has become obsolete, the warheads are returned to an explosive ordnance station and the explosive is removed by demilling. This demilling can be accomplished either by blasting with a "water jet" or actual mechanical milling on a milling machine. The first method is brute force in nature and has many limitations; the second method is dangerous in that heat can be generated by the tool thereby raising the chance of an explosion. What is needed is a system that can quickly and safely remove explosive material from warheads. This system should be capable of being submerged in water during the demilling, and should generate little or no heat at the tool/explosive interface. Ideally, this system should also be controllable in that it could remove explosives to any depth required. The system should require no pilot hole into the explosive block to start. It should also be able to enter through small inlet ports and then remove explosives from inside the shell out to four or five times the diameter of the inlet port. Ability to remove explosives in

areas of limited accessibility is a desired asset. The ideal end product would be an automated, remotely operated system that, once loaded with a warhead, would then completely demill the warhead without operator assistance.

With these objectives in mind, DAEDALEAN ASSOCIATES, Inc. (DAI) under contract to the Office of Naval Research has conducted a research effort to demonstrate the feasibility of utilizing the phenomenon of cavitation for demilling warheads.

2.0 BACKGROUND AND OBJECTIVES

DAI has successfully applied the principle of cavitation erosion for various U. S. Government agencies to many complex problems. Under contract to the Division of Geothermal Energy (DOE), DAI has successfully utilized the phenomenon of cavitation for cleaning and removing geothermal scale from pipes and system components. DAI has conducted initial research and development under contract to the Office of Naval Research (ONR) Code 221 to prove the feasibility of utilizing cavitation for ship hull cleaning. DAI has also conducted research utilizing cavitation for trenching in various sandstones, concrete, and coal for the Civil Engineering Laboratory, Port Hueneme, California. In the technique employed in these programs, water is pumped under high pressure through a properly designed pump/motor/nozzle system. The high speed jet emerging from the nozzle produces cavitation bubbles which collapse on the surface to be cleaned. The combination of cavitation and high velocity flow removes the material in an effective and efficient manner. As the high pressure jet emerges from a properly designed nozzle with a properly defined pump and motor combination, a large number of cavitation bubbles are produced in the jet. These bubbles are carried by the jet to the material surface wherein they collapse with a predetermined intensity of erosion which can be tailored for the type of material to be encountered.

Having successfully applied the principle of cavitation erosion to the problems discussed above, DAI has conducted initial research efforts to prove the feasibility of utilizing cavitation erosion to safely demill AFX-108 explosive loaded warheads. The overall objective of DAI is to design and fabricate a demilling system for Naval Ordnance Station (NOS) in demilling Maverick Alternate Warheads (MAW). This effort is broken down into two distinct phases:

Phase I - Research/feasibility demonstration

Phase II - Prototype development and field installation

This report concerns Phase I of the program. The main objectives of this phase of the program were:

1. collect the design data for erosion of the AFX-108 explosive simulant;
2. demonstrate the demilling in blocks of simulant;
3. determine the correlation between the simulant and the actual AFX-108 explosive;
4. conduct a field demonstration of the CONCAVER™ demilling system on an actual explosive loaded warhead at NOS, Indian Head.

The remainder of this report discusses the laboratory procedures and equipment, laboratory test results, design concept of apparatus built for the field test and demonstration, and the procedures and results of the field demonstration at NOS, Indian Head.

3.0 EXPERIMENTAL APPARATUS AND TECHNIQUES

3.1 Laboratory Equipment

Equipment used for the evaluation of the CONCAVER technology as a method of demilling warheads consists of: a triplex plunger pump/motor combination; an intensity test stand; a velocity calibration chamber; and an automated nozzle system test apparatus.

The triplex plunger pump was used in all of the experiments as the high pressure water supply. The pump unit shown in Figure 1 was used for single nozzle testing. The pump is capable of developing 15,000 psi nozzle pressure at a corresponding flow rate of 4 gallons per minute (gpm). A second pump unit was used for evaluation of the complete nozzle system designed for full scale demilling operations. This unit is capable of developing 15,000 psi operating pressure at a flow rate of 17.5 gpm. This pump unit is shown in Figure 2.

The intensity test stand shown in Figure 3 was used to determine the threshold intensity of erosion of the simulated explosive material. In this test, the simulant sample was secured in the apparatus and exposed to a cavitating jet of variable intensity to determine the minimum intensity of erosion required to initiate damage. The intensity of cavitation erosion with respect to nozzle distance and nozzle pressure for each nozzle applicable to the program was also established with this apparatus.

The velocity calibration chamber was used to develop the velocity profile for each nozzle with respect to pressure. The test nozzle was mounted inside the chamber and the flow from the chamber was measured. This flow condition was measured for each 2,000 psi increment from 0 to 12,000 psi. Figure 4 is the concept drawing of the velocity calibration chamber.

The automated nozzle system test apparatus was used to determine volume removal rates of different nozzles and nozzle combinations. This apparatus is used for dynamic nozzle testing on stationary samples. Through use of hydraulic motors and cylinders, the system is capable of both rotational and translational nozzle motion, as illustrated in Figure 5. Available nozzle velocities are 0 to 5 feet per minute (fpm), horizontal; 0 to 3 fpm, vertical; and 0 to 125 revolutions per minute (rpm), rotational. A control panel consisting of multidirectional valves, flow controls, and pressure gauges facilitates control of the nozzle motion. Any combination of motions is available and the speed of each motion (vertical, horizontal, and rotational) is infinitely variable within the ranges defined. The apparatus is shown in Figure 6.

3.2 Laboratory Procedures

3.2.1 Threshold Intensity of Erosion

Before it is possible to design a nozzle for a particular application, it is necessary to determine the intensity of erosion which must be generated to produce the desired results.

For this application, the minimum intensity required to erode the explosive material must be determined. Erosion intensity generated by a nozzle is measured in units of watts per meter^2 (w/m^2); a time rate at which work is done on a unit area. The total amount of work required to erode a quantity of a designated material is therefore a function of two variables--time and erosion intensity (power). It is necessary to establish a time base which remains constant in order to determine the threshold intensity of erosion of the material. The time base selected depends on the nature of each program.

After the time base is determined, the sample material is secured in the intensity test stand directly in front of the nozzle orifice. An initial nozzle distance of one inch is utilized. The nozzle is pressurized at 1,000 psi for the time period specified after which the material is inspected. If no erosion has occurred the test is repeated with pressure increases of 1,000 psi increments. When the pressure is reached which yields the desired results, the intensity of erosion generated at this pressure is measured. A description of the intensity of erosion measurement test is discussed in Section 3.2.4.

3.2.2 Nozzle Selection

After the threshold intensity of the material is known, other design requirements are identified before final nozzle selection is made. For demilling applications, the final nozzle assembly must be capable of drilling its own pilot hole in

the material. The hole must have a diameter large enough to allow the remainder of the nozzle configuration to enter. The nozzle assembly must also be capable of complete removal of material to the inside walls of the warhead. The later capability is of significant importance as it requires that the nozzle have an effective reach of 3.25 inches to remove all the material between the maximum cleaning head diameter of 3.5 inches and the inside casing diameter of 10 inches.

Having identified the performance requirements of the nozzle system, several nozzle designs are selected for testing.

Each nozzle is tested and evaluated in terms of four major nozzle performance parameters. These factors included:

1. Nozzle velocity, V_o, (infps)
2. Loss coefficient, C_v, (nondimensional)
3. Nozzle horsepower, (HP_n)
4. Intensity of cavitation erosion, I_e, (w/m^2)

The orifice area of each nozzle is accurately measured as an initial step. After this information is recorded, the nozzle is installed in the velocity calibration chamber.

3.2.3 The Velocity Calibration

Specific tests were designed in order to generate both the velocity-pressure and loss coefficient pressure relationships. With the nozzle in the calibration chamber, the pressure was increased in 2,000 psi increments from 2,000 psi to 12,000 psi. For each pressure increment, three flow rate measurements were

recorded. The repeat measurements ensured accuracy and reproducibility of the data generated. Applying this data to equation [1], the nozzle velocity as a function of nozzle pressure was determined.

$$V_o = Q(0.321)/A \qquad [1]$$

where:

V_o = nozzle velocity (fps)

Q = flow rate (gpm)

A = nozzle orifice area (in^2)

The second relationship developed from the velocity calibration data was the loss coefficient as a function of pressure. The loss coefficient (C_v) is defined by:

$$C_v = \frac{V_o}{V_{th}} \qquad [2]$$

where:

C_v = loss coefficient (nondimensional)

V_o = actual nozzle velocity (fps)

V_{th} = theoretical nozzle velocity (fps)

The theoretical velocity is defined as the velocity potential and is dependent on operating pressure. The following equation mathematically defines (V_{th}):

$$V_{th} = \sqrt{2 \cdot g \cdot \Delta P \cdot 2.3} \qquad [3]$$

where:

V_{th} = theoretical velocity (fps)

g = gravitational force (ft/sec^2)

ΔP = pressure drop across the nozzle orifice (psi) (5)

The velocities calculated from equation [1] are applied to equation [2], as are the values of V_{th} calculated from equation [3] for each pressure increment in the profile. The loss coefficient, C_v, as a function of nozzle pressure can be calculated. This nondimensional velocity coefficient is used as a performance indicator for the nozzle. An efficient nozzle will have a high C_v factor and will be constant with respect to pressure.

The nozzle power output was also obtained for each nozzle evaluated. Data obtained from the velocity calibration test was utilized to determine nozzle power from the following equation:

$$HP_m = \frac{Q \quad \Delta P}{1714} \qquad [4]$$

where:

HP_m = measured nozzle power (HP_m)

Q = nozzle flow rate for a given ΔP (gpm)

ΔP = pressure drop across the orifice (psi)

The nozzle power parameter was utilized for optimization and definition of the equipment needs for the field experimentation.

3.2.4 The Intensity Calibrations

The intensity calibrations were utilized to determine the remaining parameters of interest for each nozzle. For these

experiments, the intensity test stand was utilized. The nozzle was secured in the apparatus along with a test sample specimen. The sample material utilized for all intensity calibrations was 1/4 inch thick 1100-F aluminum plate, 6 inches square. This material was chosen because the erosion strength was a known quantity. With the nozzle and sample installed, the stand was placed in an open tank, flooded with water, and testing initiated.

The intensity calibration measured breakthrough time (B_t), which was used to calculate intensity of erosion. Breakthrough time was defined as the time required for the impinging jet to penetrate the specimen plate. Breakthrough time was measured as a function of nozzle distance for a nozzle pressure of 10,000 psi. The nozzle distance (D_n) was varied from 0.25 to 3.25 inches for the straight orifice nozzle and 0.10 to 1.00 inches for the fan nozzle. At each distance setting, three breakthrough times were measured. The additional measurements were made to ensure accuracy and reproducibility. As each breakthrough time measurement was made, the test sample was repositioned to start the next data point.

The breakthrough time was applied to the following equation which defines intensity of cavitation erosion:

$$I_e = \frac{i \cdot S_e \cdot (175.3)}{t} \qquad [5]$$

where:

I_e = intensity of erosion (w/m^2)

i = erosion depth (thickness of sample plate) (in)

t = exposure time (breakthrough time measured) (sec)

S_e = erosion strength of the material (psi)

Calculated values of I_e were plotted as a function of nozzle distance.

3.3 Laboratory Results

3.3.1 Threshold Intensity of Erosion

The time base utilized to evaluate the threshold intensity of erosion of the simulant material was two seconds, the shortest time period at which accurate measurements can be made. A longer time period was not used because the demilling system must consist of a rotating nozzle system affording minimal dwell time on the material. The threshold intensity of erosion was determined to be 1 w/m^2.

3.3.2 Nozzle Selection

Nozzles tested in the program consisted of a .052 and a .060 inch diameter straight orifice nozzle and a 70.00076 fan nozzle. The fan nozzle erodes a wide-narrow pattern as compared to the small diameter circular pattern eroded by a straight orifice nozzle. This relationship is shown in Figure 7. The fan nozzle will be positioned in the front of the demilling head and aimed along the axial center of the casing so that it makes initial contact with the material. As the fan nozzle rotates,

it will erode a "pilot" hole in the material large enough to provide clearance for the remainder of the head to enter. The straight orifice nozzles will follow the fan nozzle. The straight orifice nozzles will be used to facilitate removal of the material between the pilot hole radius and the inside wall of the casing. The straight orifice nozzles will be directed radially outward providing a spiral sweep of the casing and contents.

3.3.3 Velocity Calibrations

Each nozzle was tested as described in Section 3.2.3. The loss coefficient and measured power output as a function of nozzle pressure for the 70.00076 fan nozzle is shown in Figure 8. The average loss coefficient (C_v) for the fan nozzle is 0.85. The loss coefficient and measured power output as a function of nozzle pressure for the .052 and .060 straight orifice nozzles are shown in Figures 9 and 10 respectively. The average loss coefficient of the .052 orifice nozzle is 0.68. The average C_v for the .060 inch diameter nozzle is 0.79.

The flow requirement as a function of nozzle pressure is shown in Figure 11 for each nozzle. The total flow requirement to operate all three nozzles is also shown on the figure. The combined flow rate of all three nozzles at the maximum operating pressure of 10,000 psi is 16.5 gpm.

3.3.4 Intensity Calibrations

The .052 and .060 inch diameter orifice nozzles were evaluated at 10,000 psi nozzle pressure at nozzle distances ranging

from .5 to 3.5 inches. The maximum intensity generated by the .052 inch diameter nozzle is 5200 w/m^2 at a nozzle distance of .75 inches as shown in Figure 12. The intensity at a nozzle distance of 3.5 inches is 432 w/m^2. The maximum intensity of erosion generated by the .060 inch diameter nozzle is 3920 w/m^2 at a nozzle distance of 1.0 inch, while at a nozzle distance of 3.5 inches, the intensity of erosion is 468 w/m^2. The maximum intensity of erosion generated by the .052 inch nozzle is greater than the .060 inch nozzle, however the intensity level of the .060 inch nozzle remains higher at nozzle distances of 1.5 inches to 3.5 inches as shown in Figure 12.

The 70.00076 fan nozzle was evaluated at 10,000 psi nozzle pressure at nozzle distances ranging from 0.0 to 0.375 inches. The maximum intensity generated was 2593 w/m^2 at a distance of 0.125 inches, as shown in Figure 13. The intensity of erosion at a distance of .375 inches was 476 w/m^2. The width of the cavitation envelop at that point is 0.60 inches.

4.0 NOZZLE CONFIGURATION

4.1 Nozzle Design

The nozzle system was designed based on the data generated in Section 3.3. The fan nozzle was positioned forward of the head, centered along the axis of the nozzle lance, as shown in Figure 14. The flow of the fan nozzle was directed forward to make initial contact with the material, thus eroding a pilot hole for the head to enter. The .052 inch diameter orifice nozzle was positioned .250 inches directly behind the fan nozzle. The cavitating flow from the nozzle was directed radially outward at an angle of 90° to the axis of the lance. The outside face of the nozzle is located .300 inches from the axial center of the lance and travels in a circular path of .600 inch diameter. The purpose of this nozzle is to remove the contents of the shell from the edge of the pilot hole to a radius of approximately 6 inches. The .060 inch nozzle was positioned 1.25 inches behind the .052 orifice nozzle. The flow from the nozzle was directed radially outward at 90° to the axis of the lance, similar to the .052 inch diameter nozzle. The .052 inch and .060 inch nozzles were located 180° apart to minimize the side loading on the cleaning lance caused by nozzle thrust.

The .060 inch diameter orifice nozzle follows a circular path of 3.5 inches in diameter, the maximum diameter allowable for the cleaning head. The .060 inch diameter nozzle will remove the remaining material out to the wall of the shell casing.

A conceptual drawing of the demilling head in operation is shown in Figure 15.

4.2 Preliminary Demilling Head Evaluations

The nozzle assembly was mounted in the automated test apparatus described in Section 3.1. Initial tests were conducted on a partial shell casing obtained from NOS, Indian Head. The end plate consisting of the multihole pattern had been removed leaving a level surface of simulant exposed for testing. The nozzle assembly was mounted in the apparatus with the shell properly positioned in the tank beneath it. The tank was then flooded with water to completely submerge the sample. The initial speed settings for the nozzle assembly were 50 rpm rotational and 3 inches per minute (ipm) advancing. With the speed settings preadjusted, the nozzle system was pressurized to 10,000 psi, then activated to start the demilling process. The test was run for a 2 minute time period after which the tank was drained and the casing visually inspected. The material exposed to all three jets was removed out to a diameter of approximately 9 inches leaving a 1/2 inch thick layer of material around the perimeter of the shell. The material located between the .052 and .060 inch nozzle not exposed to the .060 inch nozzle was eroded out to an average diameter of 5 inches. The material exposed only to the leading fan jet was eroded to a diameter of approximately 1 inch and a depth of approximately 1/2 inch in front of the nozzle. Figure 15 illustrates the removal pattern of the material. During the

time interval of two minutes, the nozzle assembly penetrated into the shell 6 inches and removed approximately 20 pounds of the simulant explosive.

The test was repeated with an advance rate of 1 1/2 ipm. The rotational speed and pressure remained the same. The material passed by all three nozzles was removed completely to the steel wall of the casing and to a radius of approximately 6 inches where exposed to only the .052 inch diameter orifice and fan nozzles. In the two minute period, the nozzle assembly penetrated 3 inches into the shell and removed approximately 16 pounds of the simulant explosive.

The next test was run at 5,000 psi nozzle pressure, an advance rate of 1 1/2 ipm and a rotational speed of 50 rpm. The maximum diameter removed was 7.5 inches.

Two more tests were conducted before the nozzle system reached the end of the shell. These tests were conducted at advance rates of 1 1/2 ipm and rotational speeds of 50 rpm. The pressure was set at 7,000 psi and 9,000 psi for the tests. At 7,000 psi the maximum diameter removed was 8 inches, while the maximum diameter at 9,000 psi was approximately 9.5 inches. A summary of the data is shown in Figure 16.

The highest volume removal rate, 213 in^3/min, was achieved at 10,000 psi, an advance rate of 3 ipm and rotational speed of 50 rpm. However, complete removal was not achieved in a single pass. A 1/2 inch thick layer of material remained around the

perimeter of the shell. By slowing the advance rate by 50 percent in the second test, all the material was removed exposing the steel wall of the casing. The volume removal rate corresponding to the slower advance rate was 118 in^3 per minute, a decrease of 44 percent.

In order to optimize the volume removal rate, a complex series of testing must be conducted. Limited availability of test samples for this phase of the program made it impossible to optimize the removal rate through experimentation. Therefore, the available data was analyzed to identify the design requirements of the final cleaning head.

It was noted in the final test that when the cleaning head reached the end of the shell casing a quantity of material was not removed. Two bands of material remained intact when the nozzle system reached the shell bottom, due to the step type removal pattern of the nozzle system. This condition is shown in Figure 17. To correct the problem the final nozzle design will be modified to direct the straight orifice jets 15^{0} forward into the path of the cleaning head, as shown in the figure. The nozzle sizes remained the same as originally designed.

5.0 FIELD DEMONSTRATION HARDWARE

5.1 Remote Operated Demilling System

Utilizing the data generated in Section 4.0, a remote controlled system for advancing and rotating the nozzle into the warhead was designed. The portable unit is capable of advancing and withdrawing the nozzle at infinitely variable speeds ranging from 0 to 6 ipm and simultaneously rotating the nozzle at speeds from 0 to 50 rpm. The unit is driven by two hydraulic motors supplied through hoses from a remote location. Control of speed and direction of the motors is provided by flow control and multidirectional valves mounted on a hydraulic pump and reservoir assembly positioned a safe distance from the actual demilling unit. The portable demilling system is shown in Figure 18.

5.2 High Pressure Water Pumping System

The pressure and flow requirements for removal of the simulant explosive material was determined in Section 4.2 to be 10,000 psi at a flowrate of 16.5 gpm. The pump utilized for the field demonstration is capable of pumping 17.5 gpm at a continuous pressure of 15,000 psi. The pump will provide 20,000 psi pressure for intermittent periods. Figure 2 is an illustration of the diesel powered trailer mounted pump unit.

5.3 Laboratory Evaluation

After construction of the portable system was complete, a laboratory evaluation was conducted at DAI. The prototype system was assembled and tested on a simulant warhead provided by NOS, Indian Head.

The warhead was submerged in a test tank and the demilling system properly positioned as shown in Figures 19 and 20 to enter the shell. The advance and rotation rate of the nozzle system was adjusted to 4 ipm and 30 rpm respectively. Having made all the proper adjustments, the nozzle system was pressurized and the demilling apparatus activated. The nozzle was advanced for five minutes reaching the end of the 20 inch shell and then withdrawn for approximately two minutes at the same rate, providing double coverage of the forward 8 inches of the shell casing.

The casing was then visually inspected to determine the effectiveness of the demilling operation. The forward 8 inches of shell receiving two passes of the nozzle head was 100 percent cleaned. A layer of material approximately 1/2 inch thick remained in the section of shell receiving only a single pass of the nozzle assembly. It was concluded that the shell could be completely hogged out by providing two passes of the nozzle. This can be accomplished by withdrawing the nozzle under pressure in addition to the pass made while the system advances. The entire contents of the shell with the exception of the portion protected by the collar located at the entrance port of the casing can be removed in a time period of 10 minutes. A removal rate of 125^3/min or approximately 7.6 pounds per minute is achieved with the existing apparatus.

It was also determined that flushing the shell is not required during the demilling process. The material is pulverized

into small particles that drift out of the shell without the aid of any added water flow over the amount produced by the nozzles. Examination of the material removed revealed that approximately 75 percent by volume was in the form of small pea sized or larger granules. A sample of the removed material is shown in Figure 21.

5.4 Associate and Support Equipment

The support equipment utilized for the field demonstration consisted of a water supply pump, hydraulic pump and reservoir, hoses, and necessary hand tools and safety equipment. A tank for submerging the warhead during the demilling operation and a 208 volt, 3 phase generator was supplied by NOS, Indian Head.

The water supply pump was used to draft water from the river and supply the high pressure pumping system. A minumum positive pressure of 20 psi is required to operate the high pressure pumping system.

The hydraulic pump and reservoir with associated valving was used for remote operation of the demilling system.

A tank was provided by NOS, Indian Head to submerge the warhead during the testing. A frame was also provided to secure the casing in a fixed position within the test tank.

The 208 volt, 3 phase generator was utilized to provide the electric power required to drive the hydraulic pumping system.

6.0 FIELD DEMONSTRATION

6.1 Demonstration Schedule

The field test and demonstration was conducted following the schedule shown below:

Date	Time	Operation Sequence
5/6	13:00 to 17:00	Transport equipment to NOS, Indian Head
5/7	8:30 to 10:30	Set up and check out equipment
	10:30 to 12:00	Explosive characteristic testing
	12:00 to 13:00	Lunch
	13:00 to 14:30	Explosive characteristic testing completed
	14:30 to 16:00	Set up for hog out operation
	16:00 to 17:30	Conduct hog out operation
	17:30 to 18:30	Package equipment and depart

6.2 Test Procedures

6.2.1 Explosive Characteristics Evaluation

The explosive characteristic test was conducted on small samples of explosive material (approximately 1 ounce) to determine if the explosive sample would detonate upon impact with the high pressure cavitating jet. The .052 inch diameter orifice nozzle was selected for this test because it generates the maximum intensity of erosion developed by the demilling head.

The .052 inch diameter nozzle develops an erosion intensity of 5,200 w/m^2 at a nozzle distance of 0.75 inches and pressure of 10,000 psi.

The sample of explosive material was lodged in a 3/4 inch diameter pipe with approximately one inch of the sample extending beyond the end of the pipe. The pipe section was secured vertically in a vice. The nozzle was connected to a high pressure lance and positioned so that the jet was swept across the sample in a horizontal plane. When pressurized, the nozzle was passed halfway through the cross section of the material, allowed to dwell on the sample for approximately 15 seconds at a nozzle distance of 3/4 inches, then passed through the remainder of the sample severing it completely.

The test was conducted at pressure levels of 2,000, 6,000, 10,000, 14,000, and 18,000 psi.

A final test was conducted to determine the effect of the jet on a sample of material confined in a closed container. For this test, the explosive material was packed in a 3 inch long section of 3/4 inch schedule 40 pipe capped at one end. The nozzle was directed along the axis of the pipe so that the jet impinged directly on the material through the open end. The nozzle was pressurized at an initial position of three inches from the open end and advanced into the pipe at a rate of 4 ipm until contact was made with the pipe. The nozzle pressure used for this test was 17,500 psi.

Explosive detonation did not occur under any of the test conditions. This task was a critical milestone.

6.2.2 Full Scale Demilling

After determining that the explosive does not detonate upon impact of the cavitating jet, the system was assembled to perform a complete hog out operation of a Maverick Alternate Simulation Warhead (MASW). The hog out operation was broken down into steps as listed in Figure 22. Each test was followed by a visual examination to monitor progress made and insure that proper alignment between the shell casing and the nozzle lance was maintained.

The nozzle was positioned 0.250 inches from the surface of the explosive and subject to rotational motion only for tests numbered 1, 2, and 3. These tests were conducted to determine if the explosive material possesses the same erosion characteristics as the simulant material and if the fan nozzle would erode the required diameter pilot hole. The tests were run at pressures of 4,000 psi, 8,000 psi, and 10,000 psi, respectively. The material was removed to a diameter of approximately one inch as described in Table 1. A diameter of one inch is more than adequate for the pilot hole.

The nozzle was advanced and rotated simultaneously during the fourth test for a period of 20 seconds. The nozzle assembly advanced one inch into the shell and removed all of the material to the four inch diameter wall of the entrance port.

Test Number 5 was conducted with the nozzle assembly under constant rotation while cycling the advance function. The nozzle was advanced for a period of 30 seconds then held stationary for 30 seconds, for a total time of three minutes or three complete cycles. The advance was periodically stopped as a safety precaution to insure that the material removed while advancing was flushed out of the shell and not blocking or becoming impacted at the entrance port. Total penetration into the shell during the test was 4.5 inches. Test Number 6 was a repeat of Test Number 5 for an additional penetration of 4.5 inches. It was determined that cycling the advance function was no longer necessary because the material was flowing freely out of the shell forming no blockage or buildup problem.

Test Number 7 was performed with continuous rotation and advance for a period of 2 minutes and 40 seconds. An additional penetration of 8 inches was reached into the shell for a total of 18 inches. The test was terminated to avoid possible misalignment of the test set up caused by forcing the nozzle into the end of the shell. No accurate system of gauging the depth reached into the shell by the nozzle from the remote operator's station was available, therefore the moment of contact with the end of the shell would not be known.

The explosive material was removed to an average diameter of 9 inches in Tests 5, 6, and 7 as indicated in the table.

Test Number 8 was conducted to evaluate the effect of a second pass over the material. The nozzle assembly was withdrawn at a rate of 3 ipm for a period of 60 seconds. The nozzle assembly traveled a linear distance of 3 inches and removed all of the remaining explosive material to the wall of the shell casing.

The hog out operation was terminated at this time due to the inability to contain the removed material. The means utilized to control the explosive runoff was not adequate to contain the large volume of removed material. The test procedures were shut down in the interest of safety.

The total volume of material removed from the casing during the hog out operation was approximately 1075 in^3 (0.62 ft^3) or 67 pounds. The time required to remove the material was 7 minutes--the accumulated time while the nozzle assembly was advanced or withdrawn. A volume removal rate of 152.5 in^3/min was achieved during the test procedures.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The successful completion of the tasks in Phase I of this program has yielded sufficient engineering data to justify the following conclusions and recommendations.

7.1 Conclusions

1. The intensity of erosion required to initiate erosion of the simulant explosive material in 2 seconds was determined to be 1 w/m^2.
2. The .060 inch diameter orifice nozzle generated an intensity of erosion of 468 w/m^2 at a nozzle distance of 3.5 inches while operated at a pressure of 10,000 psi. The long range of the nozzle facilitates effective material removal between the maximum nozzle head diameter of 3.5 inches and the casing diameter of 10 inches.
3. The laboratory established removal rate of the simulant explosive material in a single pass was 118 in^3/min.
4. The optimum pressure for removing the explosive material was 10,000 psi -- the maximum desired operating pressure.
5. The flow rate of the nozzle system at 10,000 psi operating pressure is 16.5 gpm. The measured power output at these conditions is 95 hp.

6. The explosive material did not detonate at 18,000 psi, the maximum pressure capability of the system. The maximum pressure utilized for the demilling operation was 10,000 psi.
7. The plastic bonded explosive was removed from the shell by the CONCAVER technique at a rate of 152.5 in^3/min.
8. The CONCAVER technique removed approximately 84 percent of the explosive material in a time period of 7 minutes. It is estimated that the entire contents of the shell could be removed in 10 minutes.

7.2 Recommendations

1. It is recommended that the overall results of the field demonstration be considered as conclusive evidence that utilization of the phenomena of cavitation is an effective demilling technique and is superior to the methods currently employed.
2. Further development of demilling equipment and associated hardware is required in order to fully utilize the CONCAVER system as an overall demilling tool.
3. Develop an automated system which will remove all the material from the shell including the portion located around the periphery of the entrance port.

4. Design a filtering and containment system for the removed explosive material as an integral part of the system.
5. Conduct further testing to optimize the demilling nozzle system design. Further testing could result in reduced net nozzle horsepower output of the system thus increasing the safety factor against possible detonation.

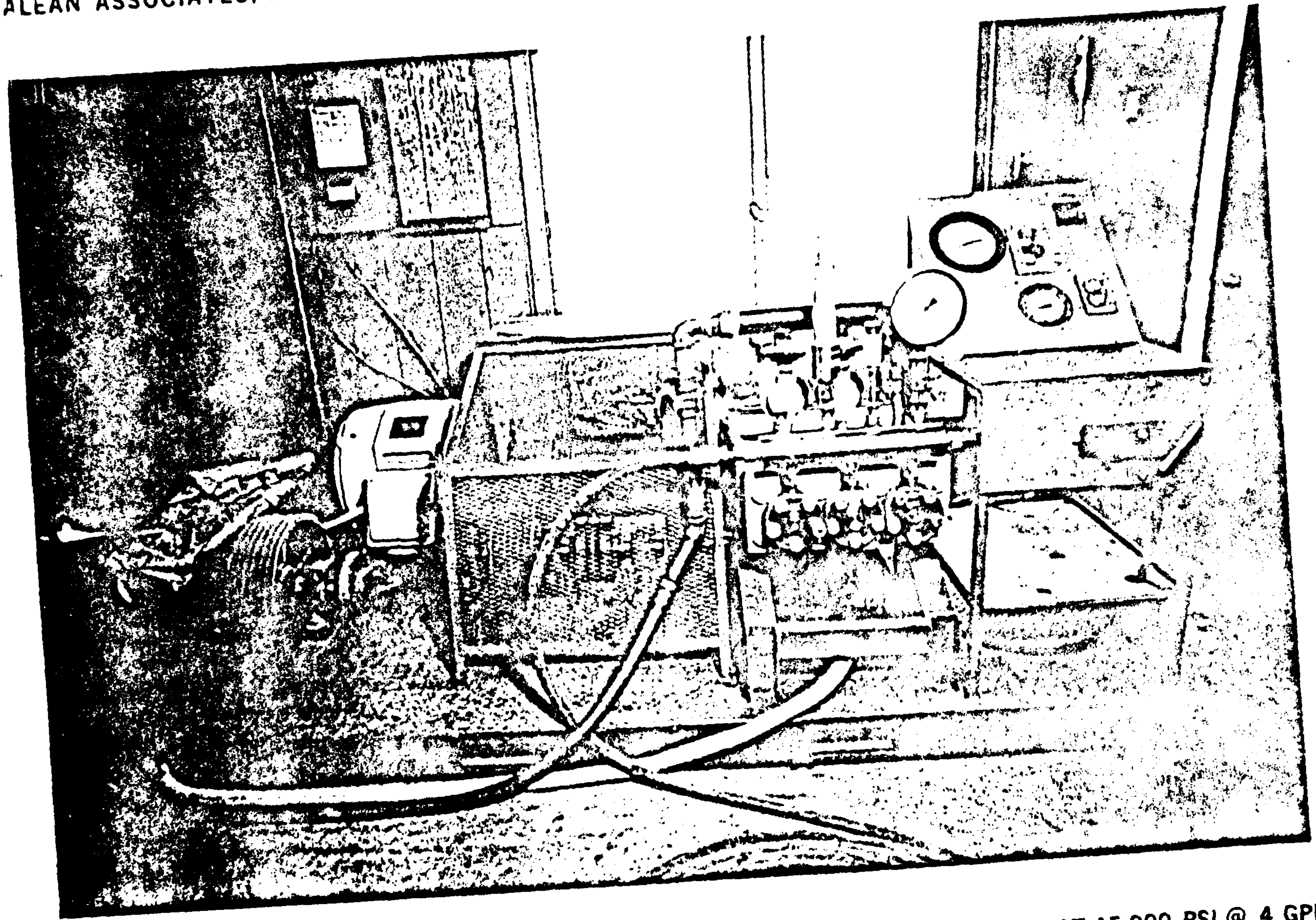

FIGURE 1 PHOTOGRAPHIC REPRESENTATION OF LABORATORY PUMPING SYSTEM RATED AT 15,000 PSI @ 4 GPM

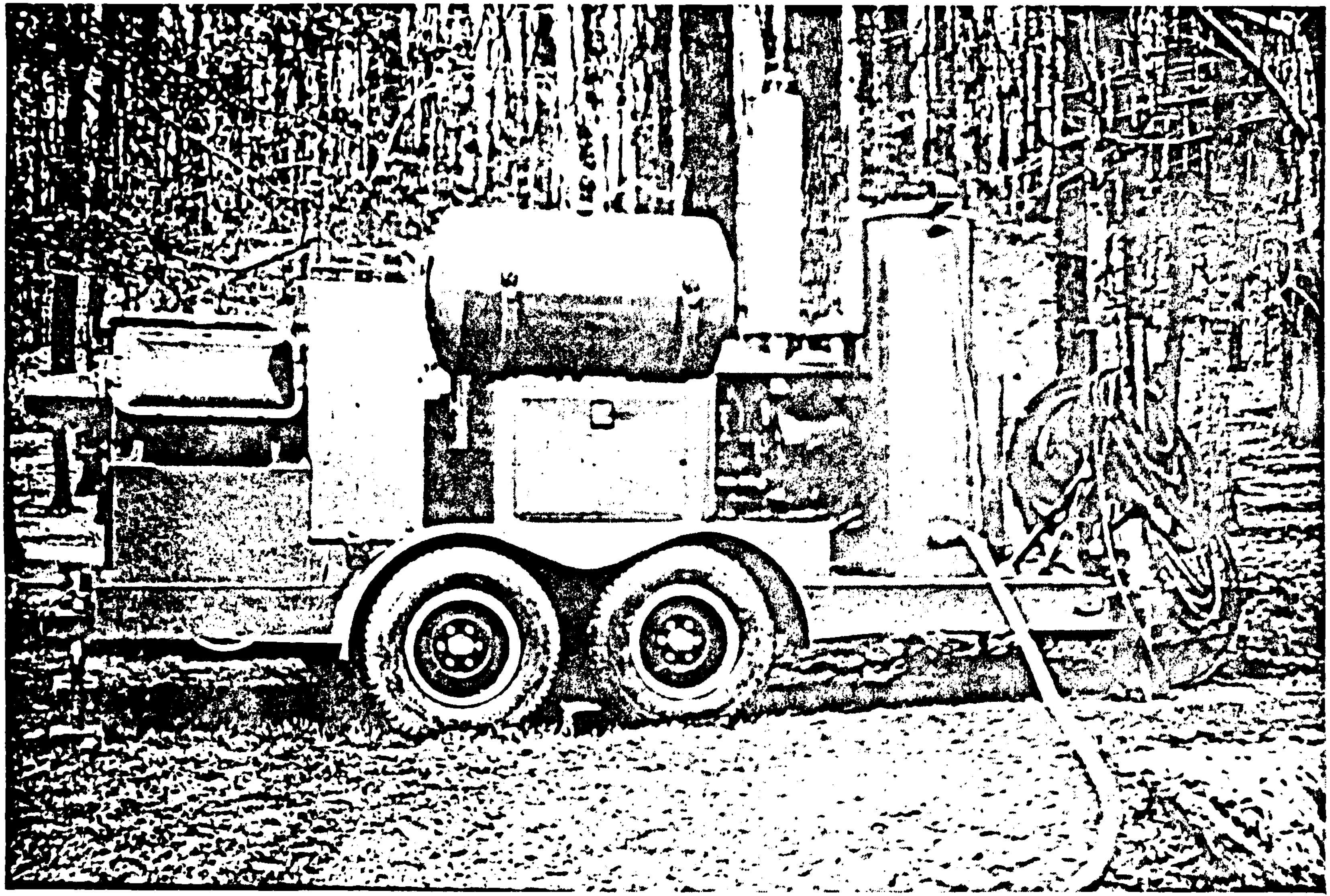

FIGURE 2 PHOTOGRAPHIC REPRESENTATION OF THE DAI HIGH PRESSURE, HIGH FLOW PUMPING SYSTEM RATED AT 15,000 PSI @ 17.5 GPM

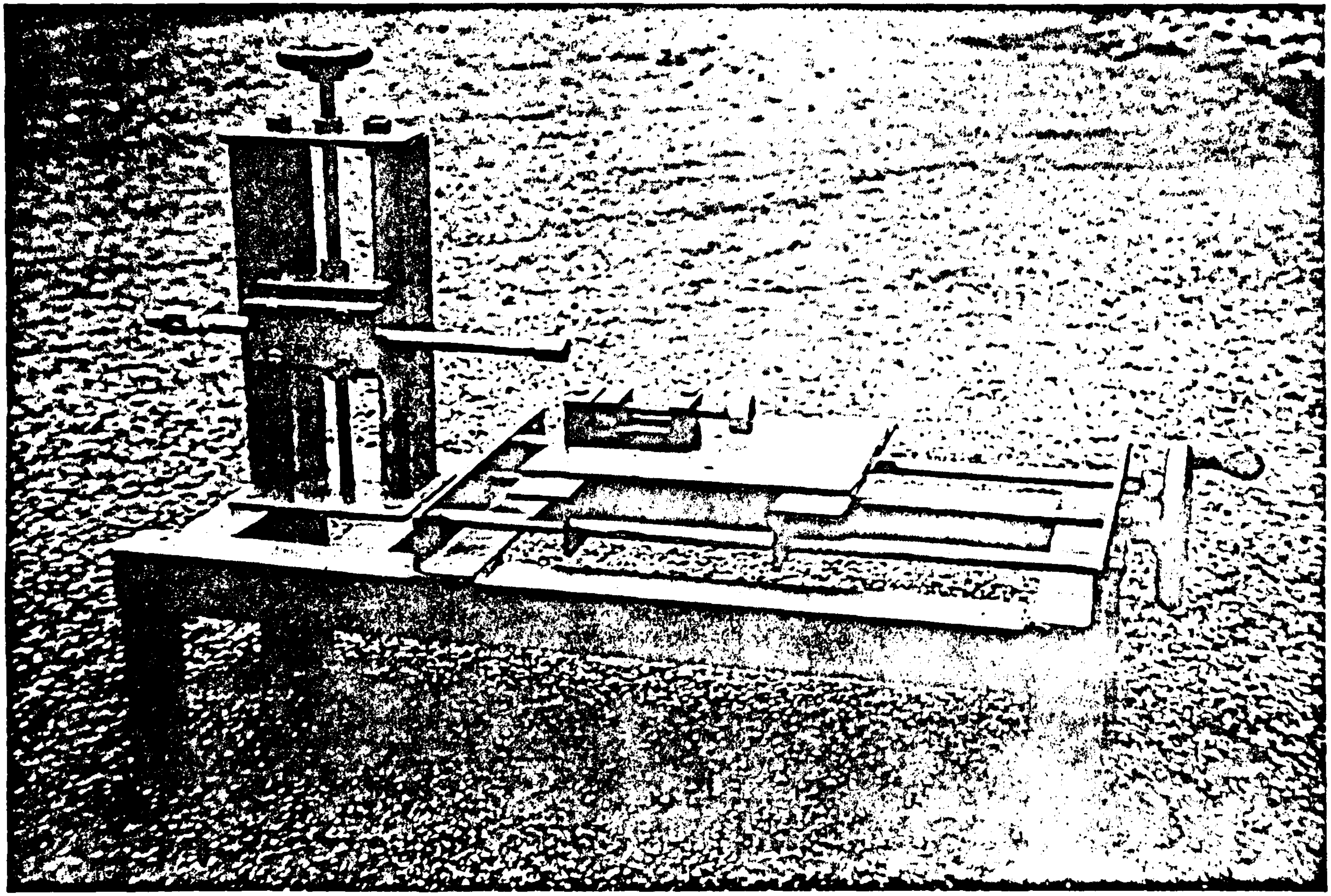

FIGURE 3 DAI INTENSITY TEST STAND UTILIZED FOR EVALUATION OF EROSION INTENSITIES

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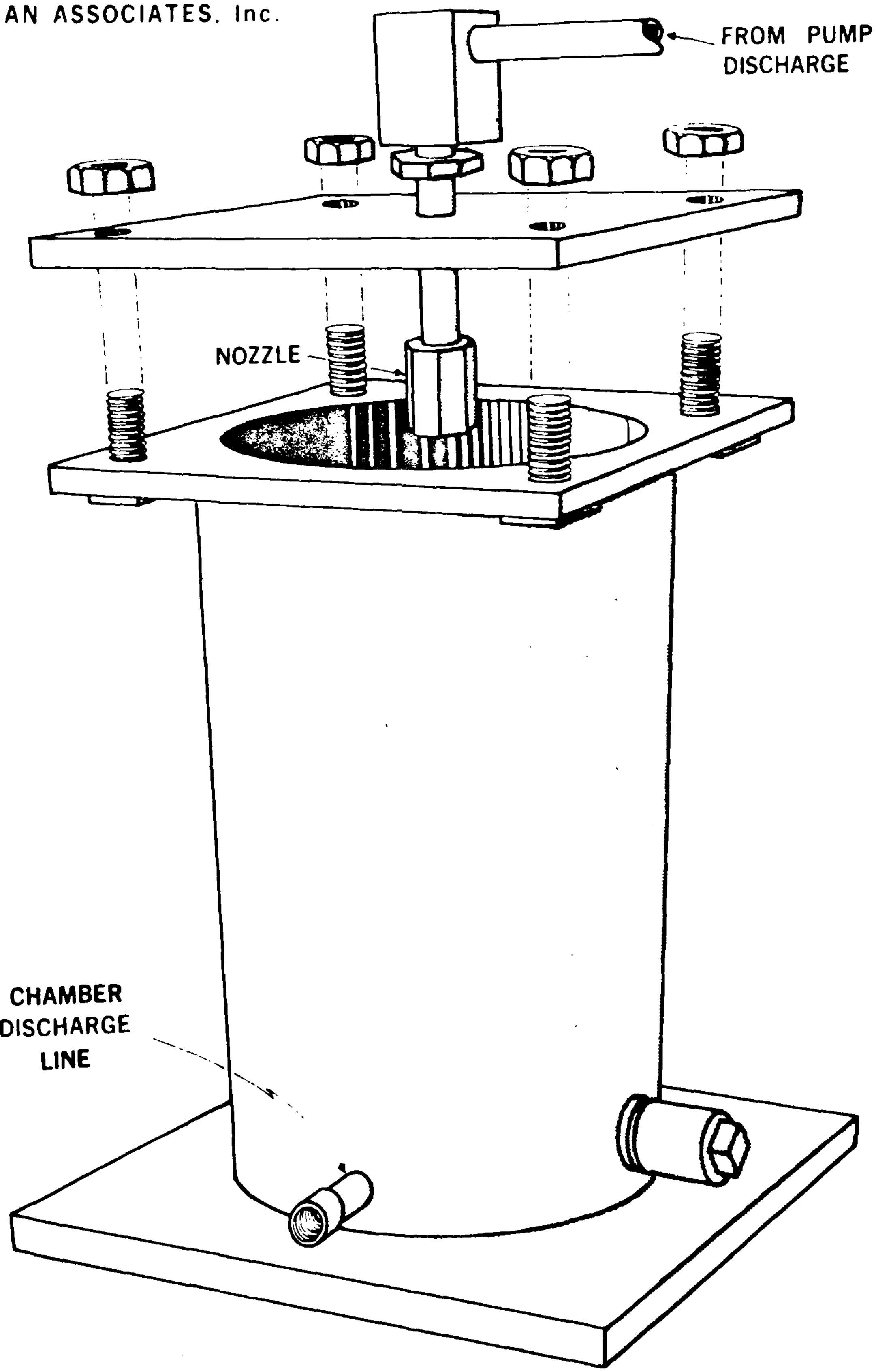

FIGURE 4 DESIGN CONCEPT DRAWING OF THE VELOCITY CALIBRATION CHAMBER

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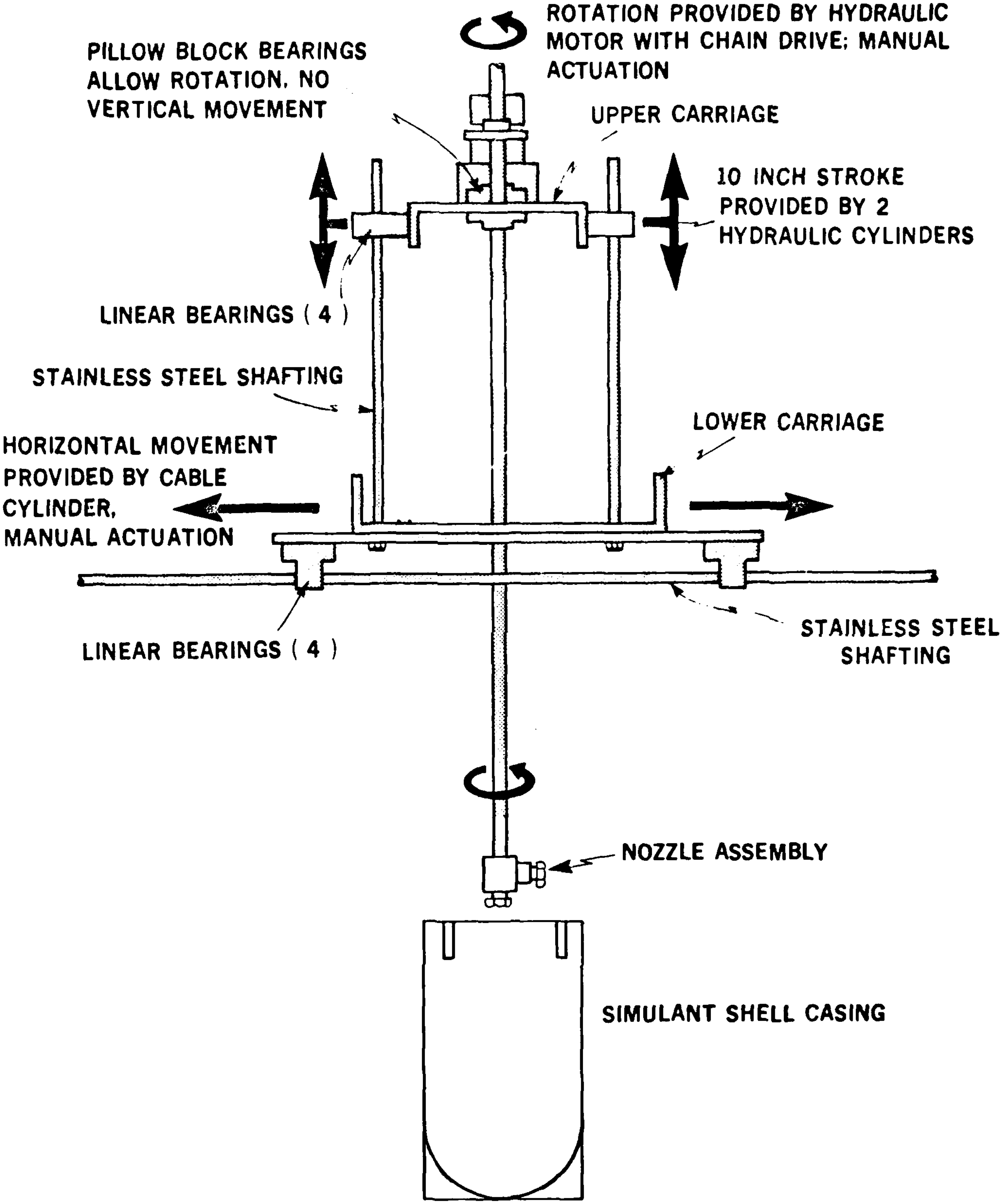


FIGURE 5 DESIGN CONCEPT OF AUTOMATED TESTING APPARATUS FOR NOZZLE ASSEMBLIES

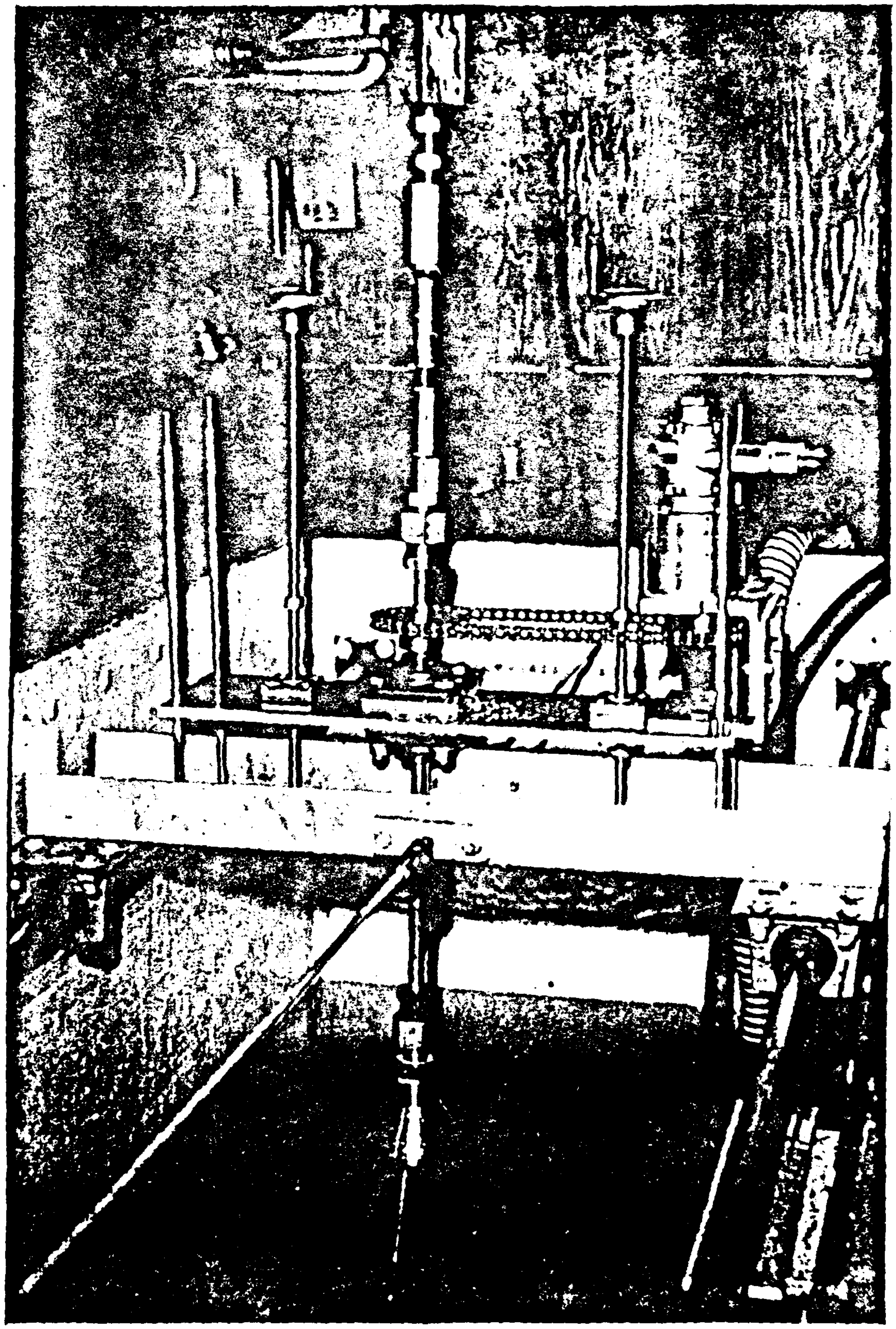
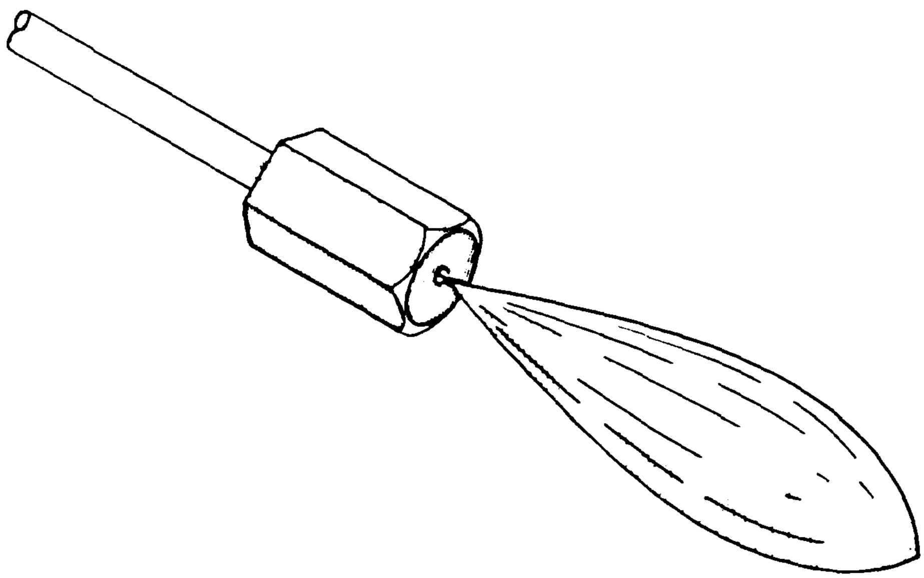
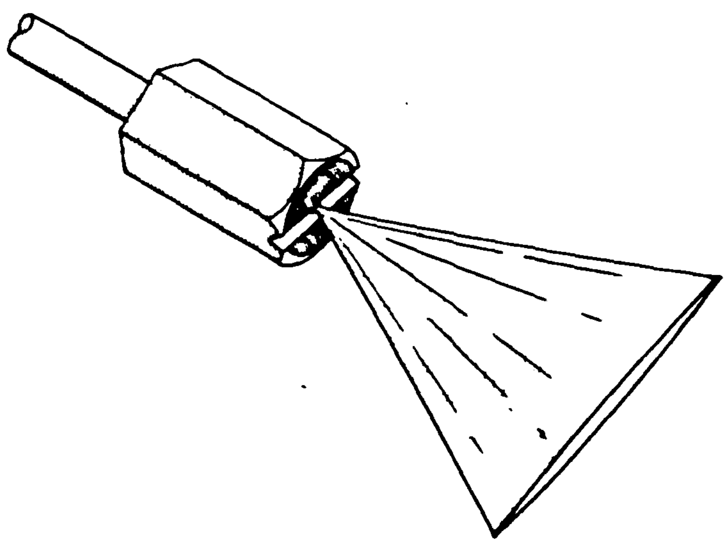


FIGURE 6 PHOTOGRAPH OF AUTOMATED TESTING APPARATUS FOR NOZZLE ASSEMBLIES AND TEST TANK



CAVITATION ENVELOPE CREATED BY THE STANDARD ORIFICE NOZZLE



CAVITATION ENVELOPE CREATED BY A STANDARD FAN JET NOZZLE

FIGURE 7 ARTIST CONCEPT OF A FAN NOZZLE COMPARED TO A TYPICAL CONICAL NOZZLE

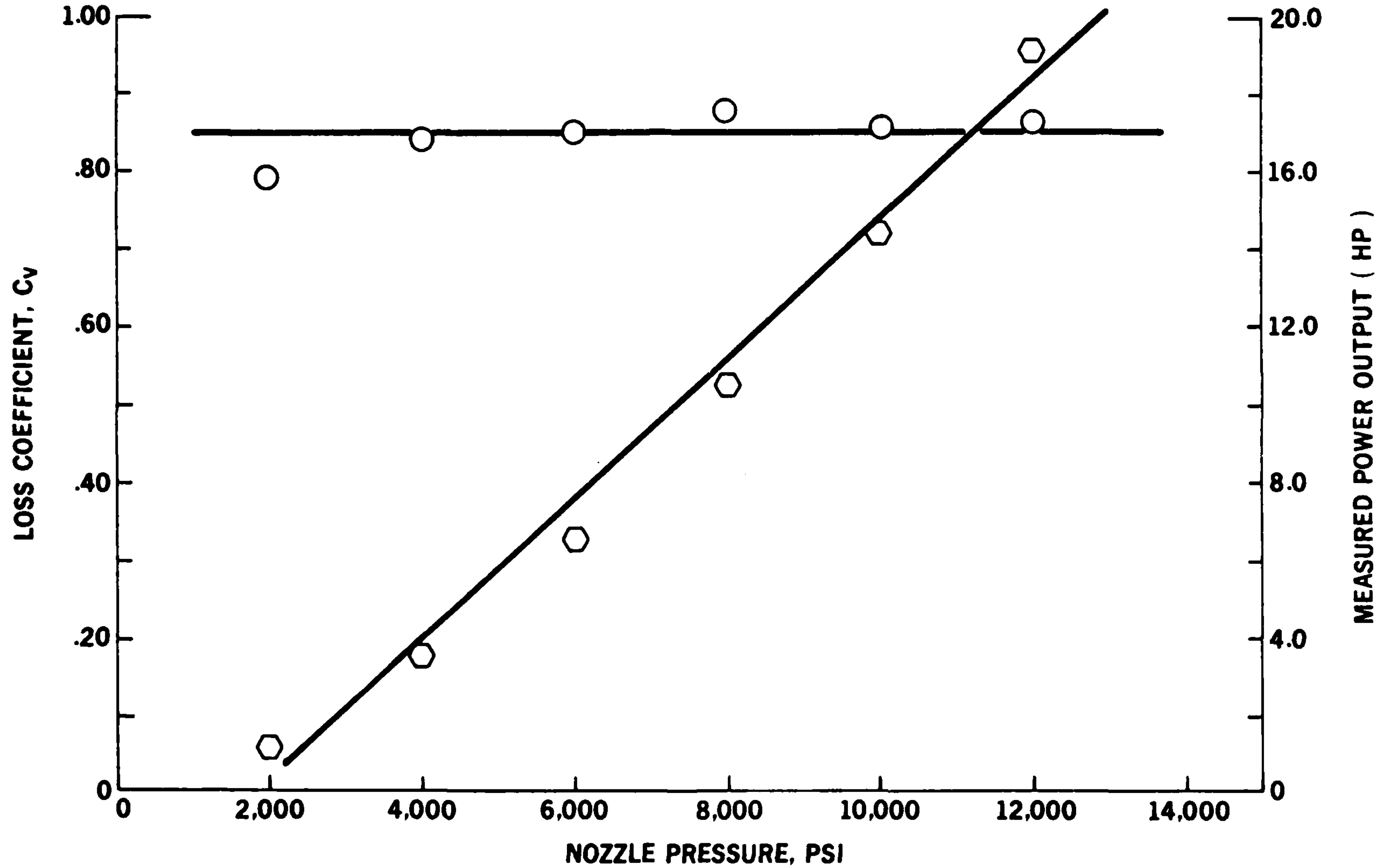


FIGURE 8 LOSS COEFFICIENT AND MEASURED POWER OUTPUT AS A FUNCTION OF NOZZLE PRESSURE FOR THE 70.00076 FAN NOZZLE

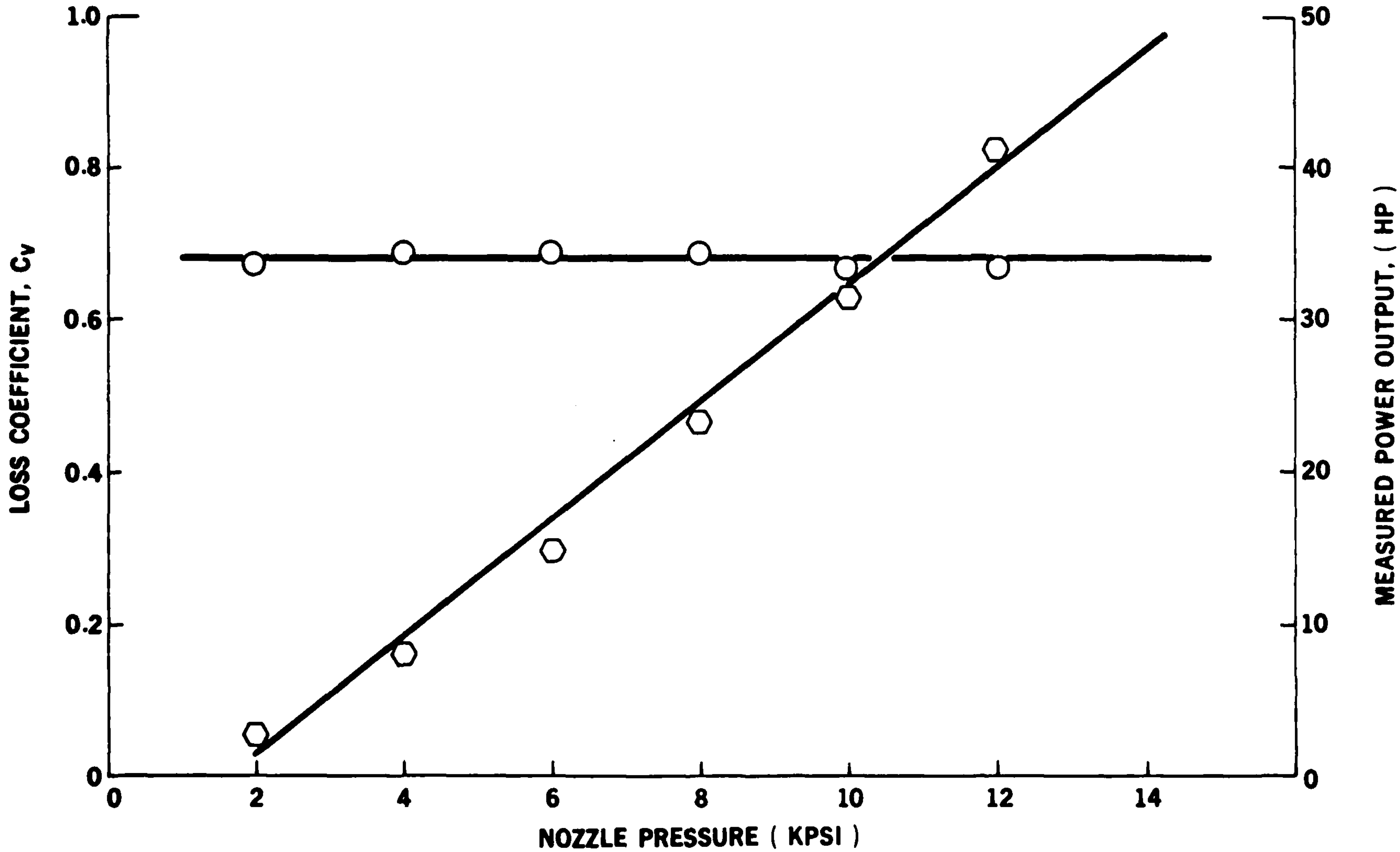


FIGURE 9 LOSS COEFFICIENT AND MEASURED POWER OUTPUT AS A FUNCTION OF NOZZLE PRESSURE FOR THE .052 INCH DIAMETER ORIFICE NOZZLE

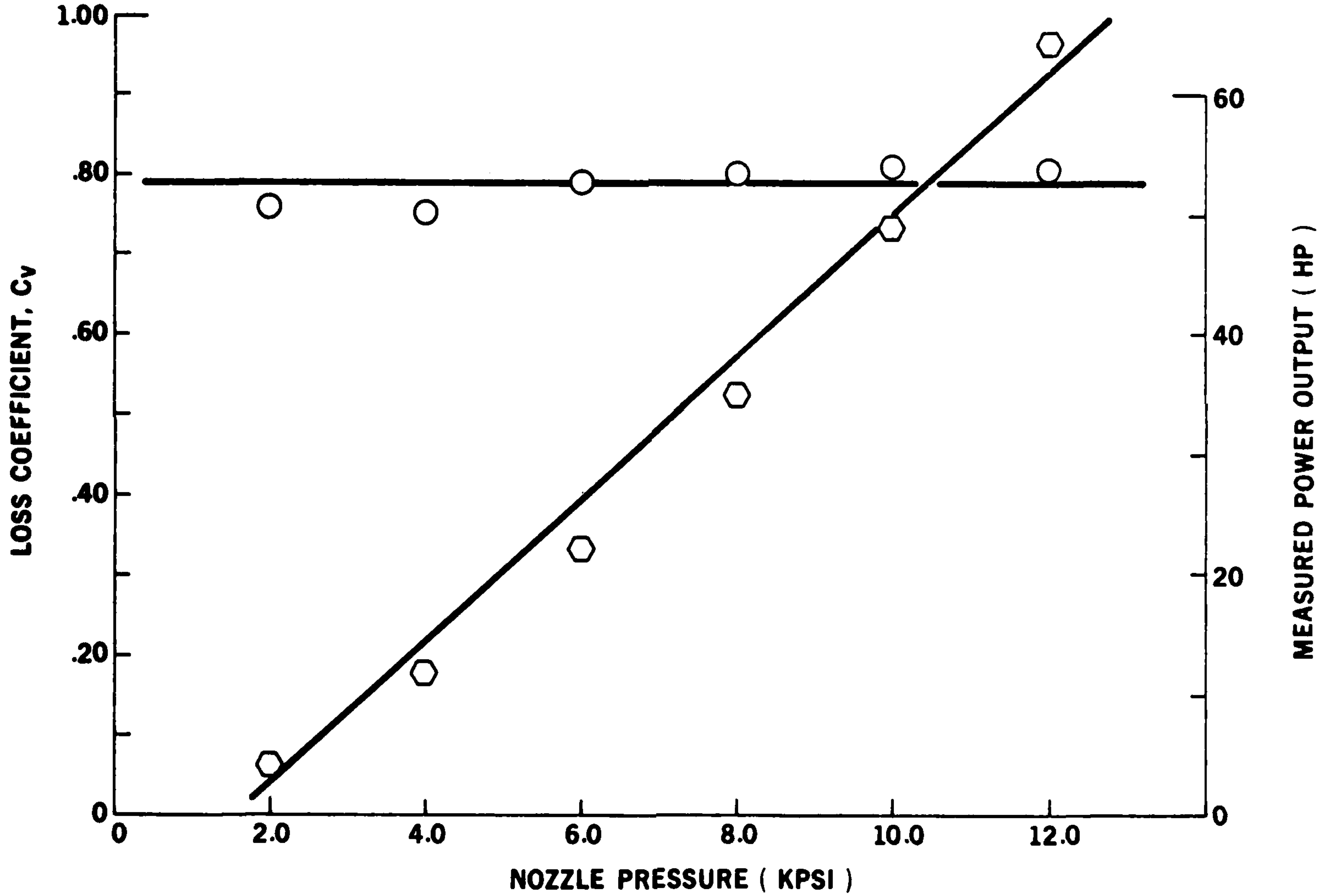


FIGURE 10 LOSS COEFFICIENT AND MEASURED POWER OUTPUT AS A FUNCTION OF NOZZLE PRESSURE FOR THE .060 INCH DIAMETER ORIFICE NOZZLE

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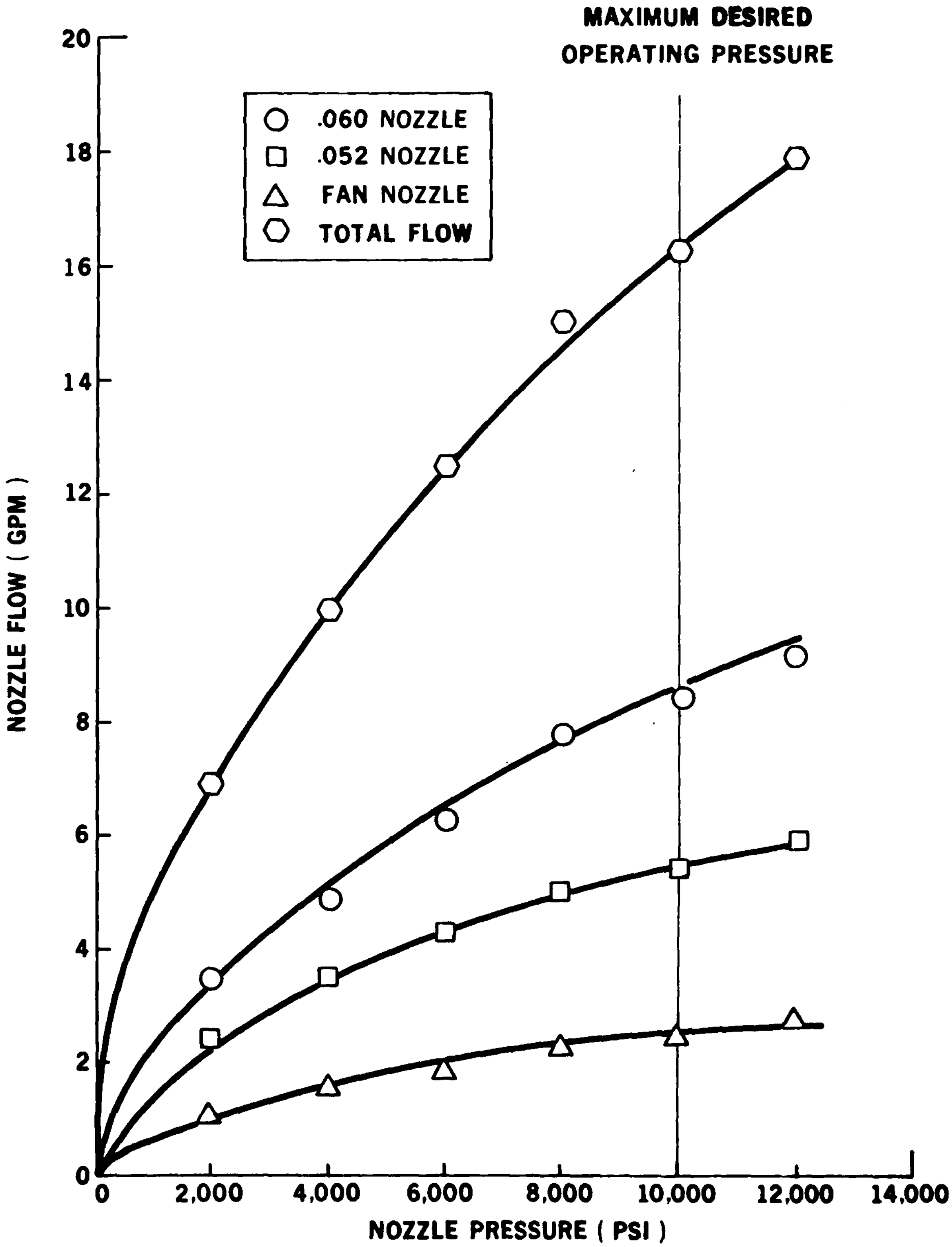

FIGURE 11 FLOW RATE AS A FUNCTION OF NOZZLE PRESSURE FOR THE NOZZLES UTILIZED IN THE PROGRAM

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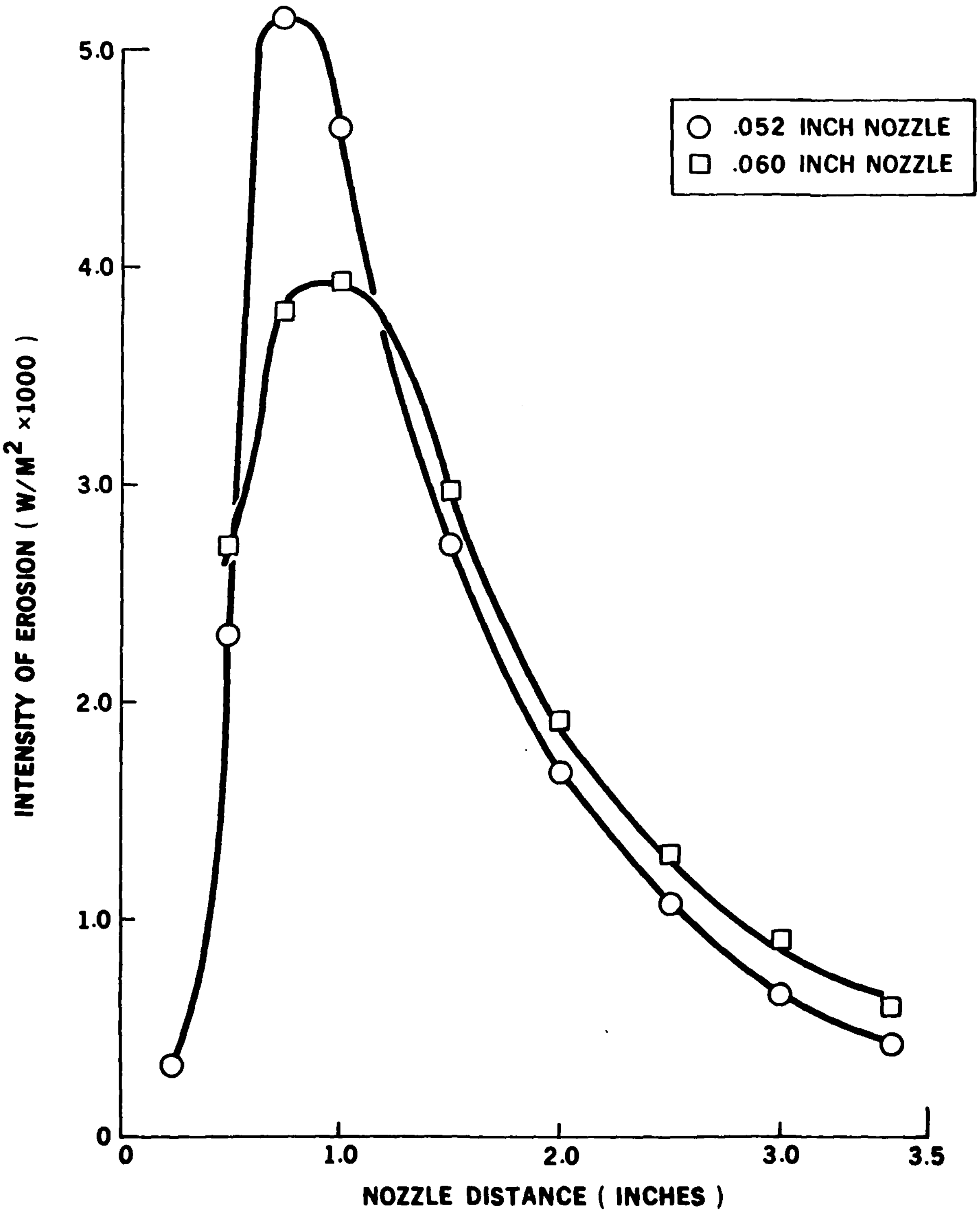


FIGURE 12 INTENSITY OF EROSION AS A FUNCTION OF NOZZLE DISTANCE FOR THE .052 AND .060 INCH DIAMETER ORIFICE NOZZLES AT 10,000 PSI NOZZLE PRESSURE

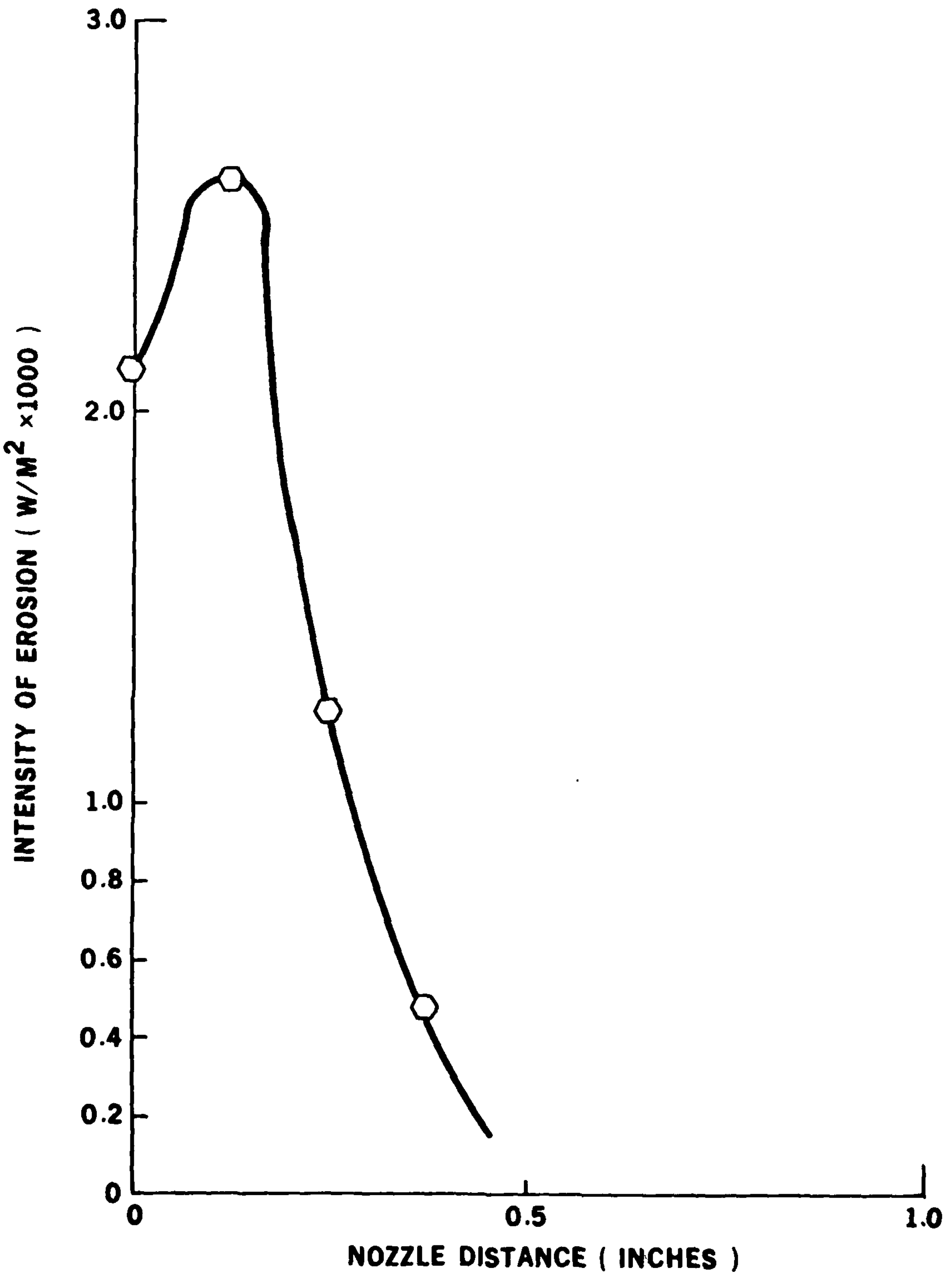


FIGURE 13 INTENSITY OF EROSION AS A FUNCTION OF NOZZLE DISTANCE FOR THE 70.00076 FAN NOZZLE AT 10,000 PSI NOZZLE PRESSURE

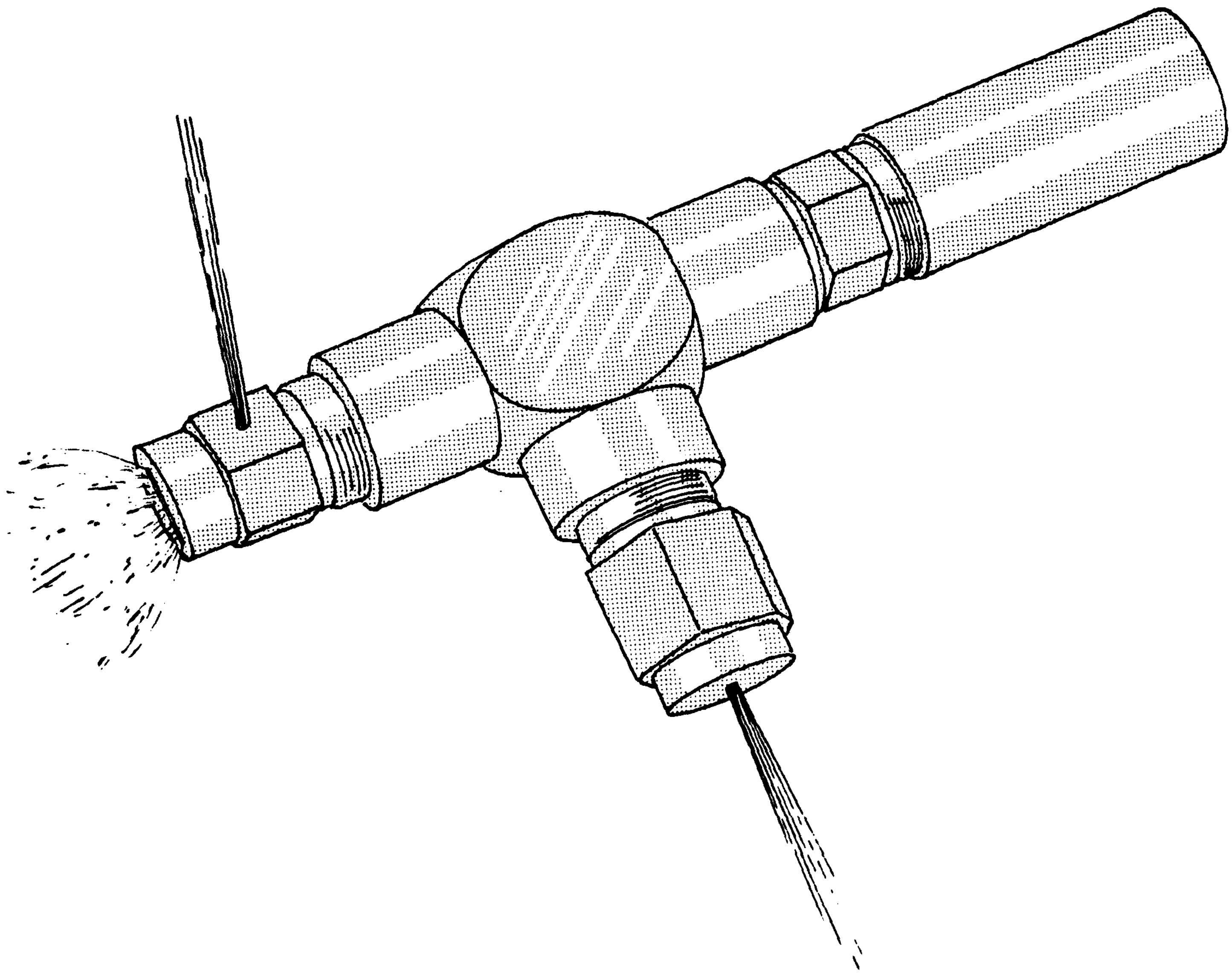


FIGURE 14 NOZZLE ASSEMBLY UTILIZED FOR LABORATORY DEMILLING RATE EVALUATIONS

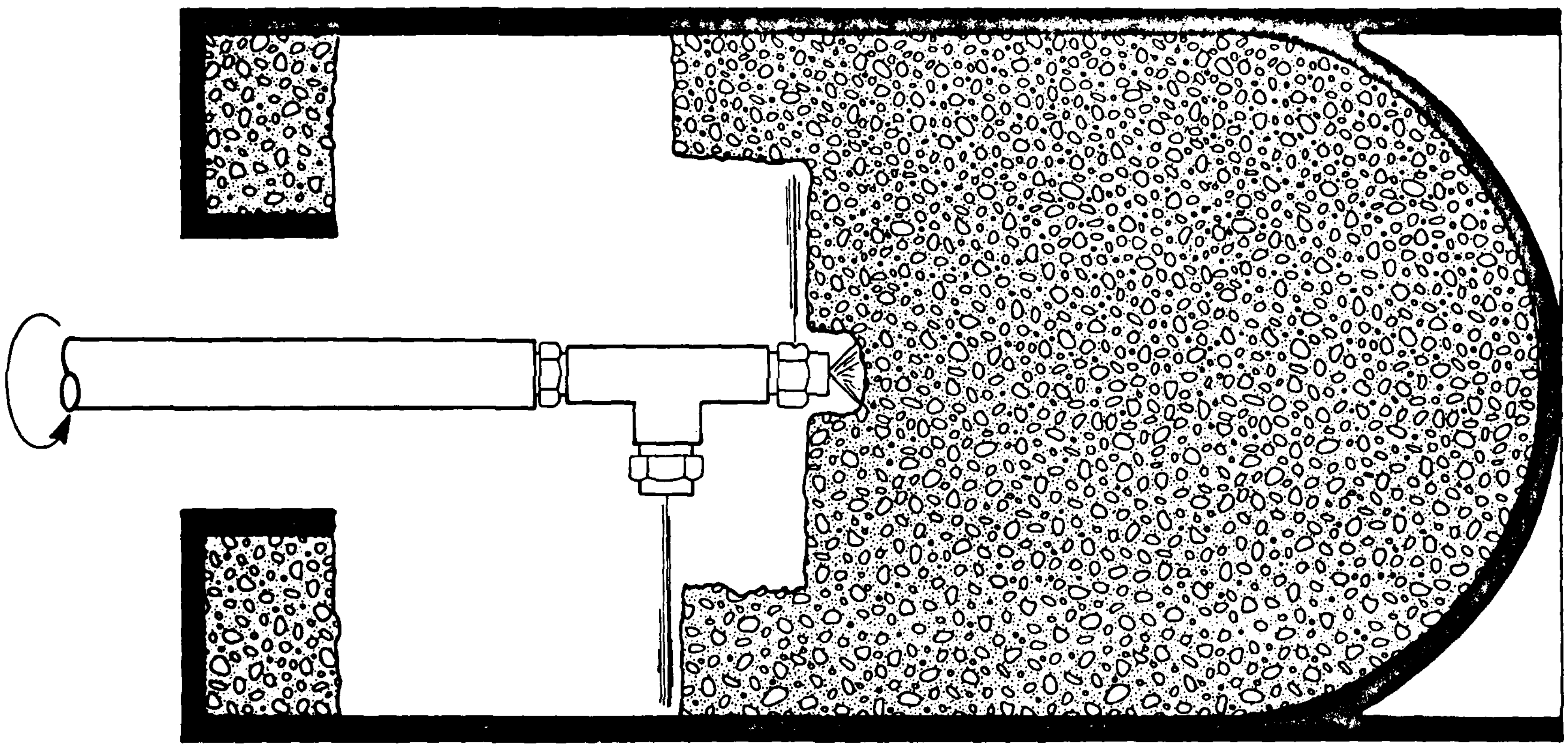
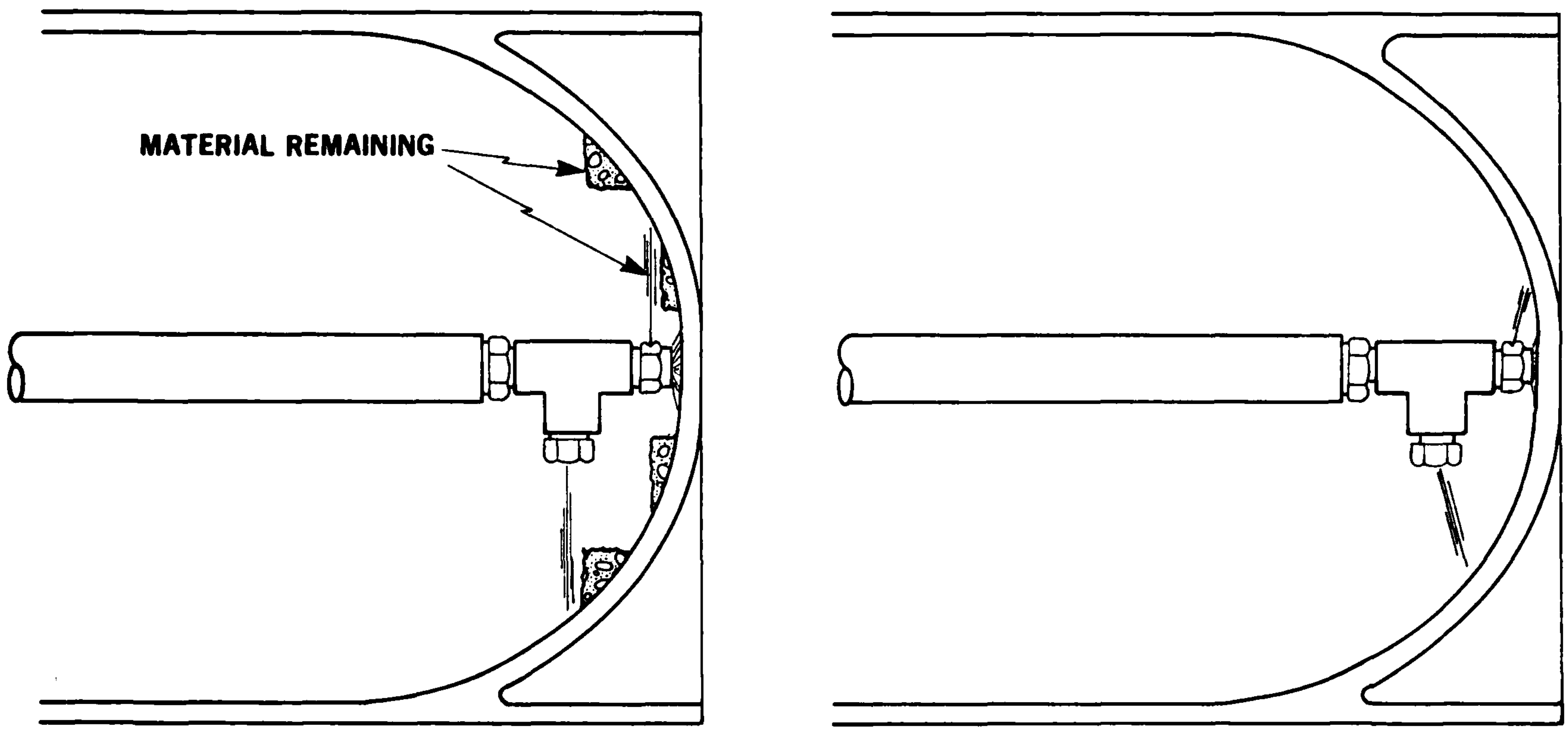


FIGURE 15 LABORATORY EVALUATION, SIMULATION OF MATERIAL REMOVAL

TEST NUMBER	ADVANCE RATE (IPM)	ROTATIONAL VELOCITY (RPM)	NOZZLE PRESSURE (PSI)	MAXIMUM DIAMETER CLEANED (INCHES)	RUN TIME (MINUTES)	VOLUME REMOVAL RATE (IN^3/MIN)
1	3	50	10,000	9.5	2	213
2	1.5	50	10,000	10	2	118
3	1.5	50	5,000	7.5	2	64
4	1.5	50	7,000	8.0	2	76
5	1.5	50	9,000	9.5	2	107

FIGURE 16 RESULTS OF DEMILLING HEAD EVALUATIONS ON A SIMULANT LOADED WARHEAD



90° RADIAL JETS

75° RADIAL JETS

FIGURE 17 MODIFICATION OF NOZZLE HEAD FOR COMPLETE REMOVAL OF MATERIAL

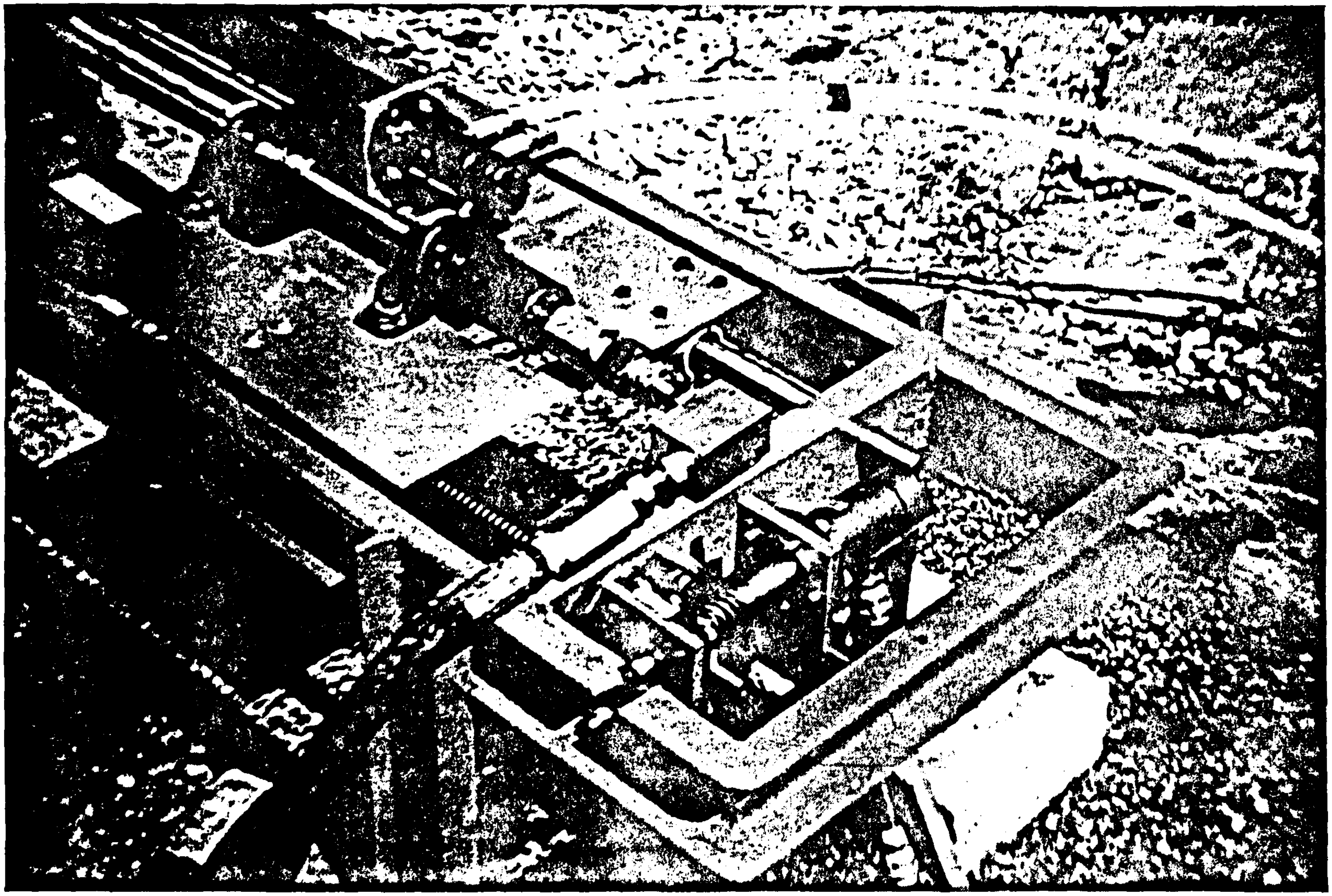


FIGURE 18 REMOTE CONTROLLED SYSTEM FOR ADVANCING AND ROTATING THE DEMILLING NOZZLE HEAD INTO THE WARHEAD

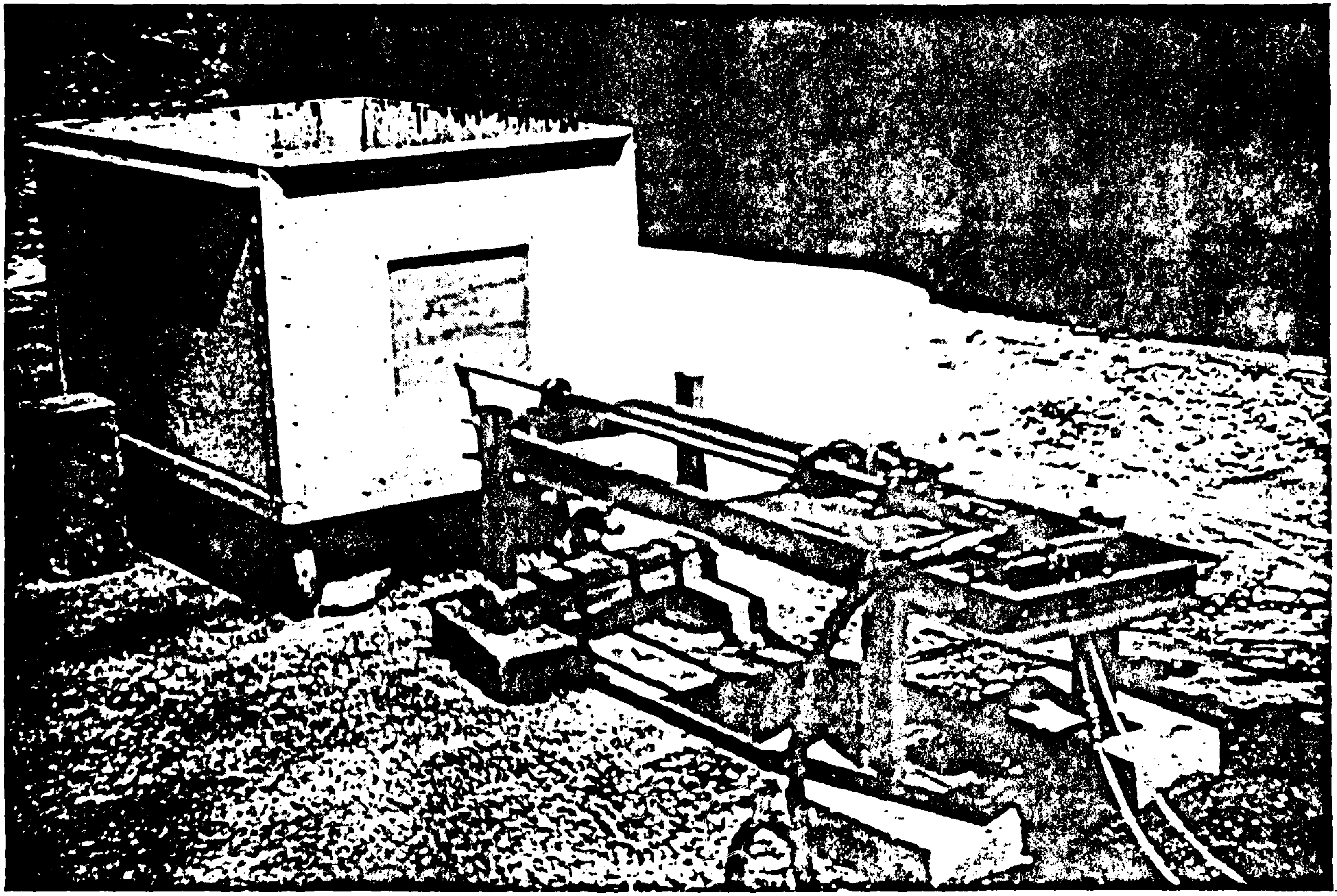


FIGURE 19 DEMILLING SYSTEM SET UP WITH HIGH PRESSURE LANCE PASSING THROUGH WALL OF TEST TANK CONTAINING SIMULANT SHELL CASING

FIGURE 20 SIMULANT WARHEAD SECURED IN TEST TANK WITH NOZZLE ASSEMBLY POSITIONED FOR DEMILLING OPERATION

FIGURE 21 SAMPLE OF MATERIAL REMOVED FROM SIMULANT FILLED WARHEAD

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TEST NO.	PRESSURE PSI ×1000	TIME	NOZZLE VELOCITY ROTATION	NOZZLE VELOCITY ADV. RATE	DISTANCE ADVANCED (INCHES)		ESTIMATED WEIGHT REMOVED (LBS.)		DIAMETER CLEANED (INCHES)	RESULTS
			RPM	IPM	TEST	TOTAL	TEST	TOTAL		
1	4	2 MIN.	25	STATION-ARY	0	0	–	–	–	ERODED SEMI - SPHERICAL SHAPED HOLE APPROX. ¼ INCH DEEP
2	8	1 MIN.	25	STATION-ARY	0	0	–	–	–	ERODED HOLE TO ½ INCH DEPTH
3	10	1 MIN.	25	STATION-ARY	0	0	–	–	–	ERODED HOLE TO ¼ INCH DEPTH
4	10	20 SEC.	25	3	1	1	0.5	0.5	4" (DIA. OF ENTRANCE PORT)	MATERIAL REMOVED TO WALLS OF ENTRANCE PORT
5	10	3 MIN.	25	3/0	4.5	5.5	17	17.5	9"	TOTAL TEST TIME WAS 3 MIN. ADVANCE FUNCTION WAS CYCLED 30 SECS. ON/30 SECS. OFF
6	10	3 MIN.	25	3/0	4.5	10.0	17	34.5	9"	REPEAT OF TEST #5
7	10	160 SEC.	25	3	8	18.0	30.5	65	9"	REACHED DEPTH OF 18" INTO SHELL
8	10	60 SEC.	25	3 (WITH-DRAWING)	3" (OUT)	–	2	67	10"	BY WITHDRAWING NOZZLE UNDER PRESSURE THE REMAINING MATERIAL WAS COMPLETELY REMOVED TO THE SUBSTRATE

FIGURE 22 SUMMARY OF RESULTS OF THE HOG OUT OPERATION PERFORMED ON THE MAVERICK ALTERNATE SIMULATION WARHEAD (MASW)